HIGHLY EFFICIENT CRYOGENIC THERMAL INSULATION FOR OPTICAL DEVICES AND PIPELINES

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UDC 536.021:536.48

Experimental results are presented on the improved efficiency of shielding vacuum thermal insulation (SVTI) with gaskets fabricated from polyethyleneterephthalate (PET) film treated with antistatic substances (surface-active substances (SAS)) for reduction of electrostatic charges and contact heat transfer (by 30% or more).

In a number of cryogenic optical devices, pipelines, medical cryoinstruments, and cryogenic reservoirs, shielding vacuum thermal insulation is used with gaskets fabricated from polyethyleneterephthalate film. This SVTI possesses reduced gassing and soiling and better durability, which makes it possible to implement automatic coiling [1, 2]. The efficiency of this insulation is due not only to the aforementioned advantages but also to the fact that its thermal characteristics are close to those of its most efficient analogs: the minimum thermoconductivity coefficient is $(0.3-0.5)10^{-8}$ W/(m·K). However, the efficiency of the given type of insulation, as is shown by preliminary studies [3, 4], can be increased substantially by thermal pre-treatment of SVTI along with the article under atmospheric conditions. In this case the contact thermoconductivity, for example, for the given composition decreases by more than half.

Operation of SVTI with PET gaskets has shown that the PET film sticks to the hands upon mounting, whereas in the insulation layers sticking of the metallized shield to the film without deposition is observed. This sticking can be explained only by the presence of considerable opposite electrostatic charges on the surface of the insulating materials. Therefore, the investigation of this phenomenon and its effect on the contact heat transfer in SVTI is of considerable interest. In addition, the problem of changes in PET film absorbance as a function of its structure and degree of crystallinity and the effect of this optical parameter on radiative heat transfer in SVTI is still not investigated.

In the present work investigations are continued on use of various new technologies to improve the efficiency of shielding vacuum thermal insulations with PET film gaskets as a result of a decrease in both the contact and radiative heat transfer. In this connection measurements of charges at surfaces of shields and gaskets were performed, and it was established for the first time that electrostatic charges that appear in the process of fabrication of the insulation affect adversely the heat transfer in SVTI. The charge measured at the room temperature does not vanish and acts for a long time in the course of thermal tests even at low temperatures. The value of the electrostatic charge at the surface of the gasket (fabricated from PET film) and at the surface of the shield fabricated from a film with double-sided Al deposition (PET DA) was measured using a digital electrostatic field sensor (TsEP-3). The effect of various factors on the magnitude of the electrostatic charge was studied: polymer film thickness, treatment of the polymer with various antistatics (surface-active substances, SAS), deposition, and friction.

Measurements of the charge values have shown that the charge on the gasket fabricated from PET is tenfold greater than that on the shield (from the same film but Al-deposited). Only the gaskets were treated with the antistatic substances since the SAS treatment of the shields affected adversely their reflective properties. In order to decrease the contact heat transfer in SVTI, two approaches to changing of the electrostatic charge value at the gasket surface were chosen: charge value reduction using antistatic treatment of the PET film and increase in the

B. I. Berkin Physicotechnical Institute of Low Temperatures, Kharkov, Ukraine. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 68, No. 1, pp. 51-54, January-February, 1995. Original article submitted October 6, 1993.

 1062-0125/95/6801-0046$12.50

TABLE 1. Values of the Surface Electrostatic Charge Density σ, C/m^2, for PET and PET DA Films of Various Thickness

Thickness δ, μm	Surface deposition	Surface treatment	Charge density at the surface σ, C/m^2
6	–	As shipped	$0.59 \cdot 10^{-7}$
6	Al on both sides	Deposition 400-600 Å	$0.24 \cdot 10^{-8}$
6	–	Rubbing against fur 10 times	$0.19 \cdot 10^{-6}$
6	–	Rubbing against fur 20 times	$0.21 \cdot 10^{-6}$
8	–	As shipped	$0.47 \cdot 10^{-7}$
8	–	"OS" antistatic substance	$1.0 \cdot 10^{-8}$
8	–	"Lana-1" antistatic substance	$0.55 \cdot 10^{-8}$
8	–	"Domol" antistatic substance	$0.66 \cdot 10^{-8}$
10	–	As shipped	$0.38 \cdot 10^{-7}$
12	Al on both sides	Deposition 600-800 Å	$0.15 \cdot 10^{-8}$

charge value by rubbing the films against fur (wool) [5]. A decrease in the value of the electrostatic charge leads to a decrease in the sticking in the layers of the shield with the gasket with opposite charged surfaces, whereas an increase in the charge values leads to a decrease in contacts between two PET films in the case of the use of two gaskets with equally charged surfaces. Results of the measurements are listed in Table 1. As is seen from the table, Al deposition is favorable to the discharge of the static electricity, and therefore the value of the charge on the shield is tenfold lower than on the gasket. With an increase in the polymer film thickness from 6 to 10 μm the charge value decreases approximately 1.5-fold, which can be explained by the distinctive features of the polymer material conductivity [6]. Treatment of the PET film with antistatics reduces the electrostatic charge at its surface more than tenfold (from $0.52 \cdot 10^{-7}$ to $0.26 \cdot 10^{-8}$ C/m^2).The best result in the reduction of the electrostatic charge value on the gasket was obtained after its treatment with the domestic antistatic "Lana-1." However, the disadvantage of this antistatic is the "stickiness" of the substance deposited on the film after sprinkling.Therefore the German-made "Domol" SAS was used thereafter to reduce the charge of the gasket in insulating a pipeline.

Thermal tests of insulation 5 mm thick with a stacking density of 18 shields/cm with shields of PET DA and gaskets from crumpled film were carried out on a liquid nitrogen pipeline 8 mm in diameter and 1 m in length. Of the two approaches to the problem of the reduction of contact heat transfer in the insulation (a decrease in the charge on the film to $\sigma < 1 \cdot 10^{-8}$ C/m^2 by antistatic treatment and a 30-fold increase in the charge on the gaskets in the arrangement with two gaskets between the shields) the first one turned out to be more efficient (the heat flux to the cryogenic pipeline decreased by 28% compared to 13.5% in the latter case). However, as was shown by preliminary studies with the use of other technologies for the reduction of the electrostatic charge on the polymer materials, the effect can be even higher (up to 36%) upon a reduction solely of the charge on the gasket to $\sigma \leq 1 \cdot 10^{-9}$ C/m^2 (see Fig. 1).

To reduce the radiative heat transfer, investigations on determination of the effect of a technological procedure such as high-temperature thermal pre-treatment of the PET film gasket on its optical properties, namely PET film absorbance of IR radiation were carried out. It was found experimentally that by changing the heating time of the PET film at the temperature of the maximum crystallization rate in air the degree of crystallinity can

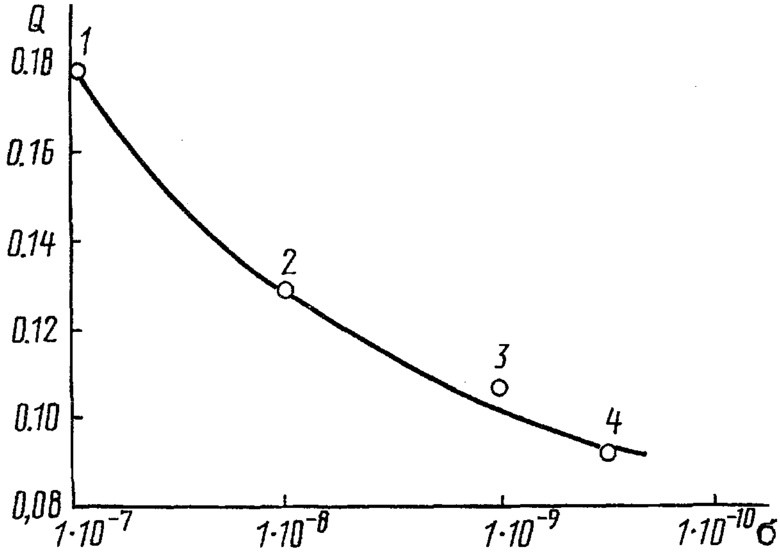

Fig. 1. Dependence of the heat flux Q, W, toward a cryogenic pipeline with PET DA + crumbled PET insulation on the electrostatic charge on the PET film gasket: 1) insulation without treatment; 2) insulation with a PET film treated with "Domol" antistatic substance; 3) insulation with a PET film treated according to the method of [9]; 4) special PET film treatment.

TABLE 2. Heat Flux Q, W, toward a Cryogenic Pipeline 8 mm in Diameter and 1 m in Length with Liquid Nitrogen with PET DA + Crumbled PET Insulation for Various Heat Treatment Regimes for a PET Film 6 μm Thick

Heating time τ, sec	Heating temperature T, °C	Heat flux Q, W	Heating time τ, sec	Heating temperature T, °C	Heat flux Q, W
1800–5400	120–140	0.128	40.0	180	0.106
1.0	180	0.178	120.0	180	0.112

be affected [8], and consequently optical and, ultimately, thermophysical characteristics of the PET film and the insulation as a whole can be affected as well. It is seen from a comparison of results of thermophysical experiments for the considered insulation of the aforementioned cryogenic pipeline (Table 2) that the optimum heating time at the temperature of the maximum crystallization rate is a time equal to the crystallization half-period (insulation efficiency is increased by 13% [9]). This can be explained by the fact that within this time interval complete crystallization is not achieved, the crystals formed do not reach their maximum dimensions, and the scattering of thermal radiation is insignificant. It was found by the method of small-angle scattering that the PET film possesses a spherolite hypomolecular structure, with spherolite dimensions dependent on the temperature-rate regime of their formation and lying within the limits from fractions of a μm to 10 μm. The scattering was found to be insignificant for IR radiation with λ_{max} = 10 μm (at 300 K) for specified dimensions of the crystals of less than 10 μm. With the chosen heat treatment regime a decrease was found in the absorption of thin (6-12 μm) PET films (by ellipsometric studies and IR spectroscopy).

Thus, the efficiency of SVTI with gaskets fabricated from polyethyleneterephthalate film with decreased gassing and soiling and improved technological effectiveness as a result of higher durability parameters of the film (compared to glass paper and basalt paper) can be improved substantially with the use of treatment technologies that are not traditional for SVTI. In addition to the joint thermal treatment of SVTI along with the article under atmospheric conditions [4] the use of pre-treatment with antistatic substances prior to mounting of the PET film is recommended in order to eliminate static electricity and reduce the contact heat transfer in SVTI (by almost 30%), and thermal treatment of the PET film is recommended to decrease its absorption of IR radiation and consequently decrease the radiative heat transfer in SVTI [9]. Investigations on reducing the electrostatic charge values on both the gasket and the shield should be continued with the use of new technologies forimproving the efficiency not only of the insulation arrangement under consideration but of other SVTI arrangements as well.

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